Effect of S and O on the Creep Properties of Zirconium Alloys

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1. Introduction

Zirconium alloys have been widely used for the fuel cladding and other core components in a nuclear reactor and among them Zircaloy-4 has been mainly used as a fuel cladding material for the pressurized water reactors (PWR) for a long time. However, since the PWR operating conditions such as a higher burn-up, increased operating temperature and a high pH operation have been implemented to improve a reactors efficiency, advanced Zr-based alloys have become necessary. Most of the alloying elements were added to the zirconium alloys to increase the corrosion resistance and the creep strength. It is well known that the creep strength of zirconium alloys is affected by alloying elements such as tin [1, 2], oxygen [2], carbon [3], niobium [4] and sulfur [5, 6] in a solid solution state. The present work was undertaken to study the sulfur or oxygen effect on the creep behavior of Zr-1.8Nb based alloys.

2. Experimental procedure

2.1 Test Specimen Preparation

The chemical compositions of the Zr-based alloy used in this study are the Zr-1.8Nb-xO (x = 0.074, 0.122, 0.144, 0.17) alloys and the Zr-1.8Nb-0.144O-yS (y = 0, 0.00059, 0.00154, 0.00248). The alloy sheet for a creep test was manufactured by the process of a beta-quenching, hot and cold rolling with a intermediate annealing. The final annealing was performed at 510℃ for 8 hours to obtain a recrystallization microstructure. Fig. 1 shows the test specimen preparation process.

2.2 Creep Tests

Creep specimens were machined from the sheet along the RD direction with a gauge length and width of 25 mm and 5 mm, respectively. Creep tests were carried out under a constant load condition at a temperature of 350℃ and the stress ranges from 90 to 130MPa. The axial creep strains were monitored by using an LVDT (Liner Variable Differential Transformer) extensometer. Creep samples were tested at a given temperature for 144 hours to reduce the creep exposure time.

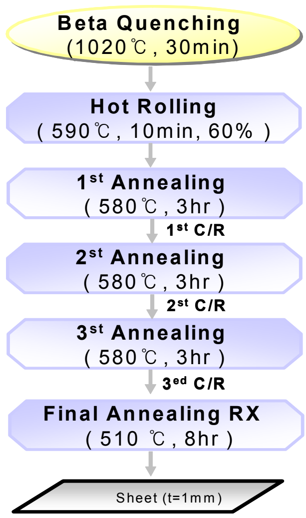

Fig 1. The test specimen preparation process

3. Results and discussion

3.1 Thermal creep behavior of Zr-based alloys

Generally, the creep behavior of Zirconium alloys was affected by certain parameters such as the chemical composition, texture, and microstructural characteristics of the grain size, and the dislocation density. Fig. 2 shows the creep curves of Zr-based alloys with different applied stresses and different additional alloying elements.

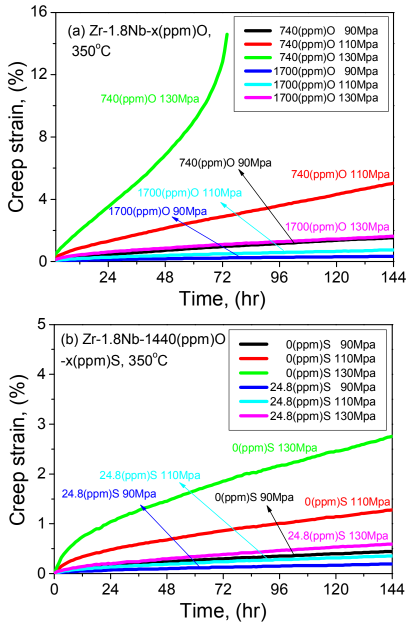

Fig 2. Thermal creep properties of the Zr-based alloys with a different applied stress, test at 350℃

The creep strain of the Zr-1.8Nb-xO alloys (a) and the Zr-1.8Nb-0.144O-yS alloys (b) are shown Fig. 2. The normal creep curves containing a steady state region were observed during the creep test. The tertiary creep regime was observed in the Zr-1.8Nb-0.074O alloy which was tested in the temperature of 350℃ at an applied stress of 130MPa. The creep strain of between O containing alloys and S containing alloys was quite different at the same applied stress. At each applied stress of 90, 110 and 130 MPa, the creep strain of the Zr-1.8Nb-0.144O-xS alloy was about two times higher than those of the Zr-1.8Nb-xO alloy.

3.2 Stress exponent

The stress dependency of the creep rate is obtained from the double log plots as a function of the creep rate and stresses. Fig. 3 shows the log-log plot with the creep strain rate and the applied stress of the Zr-based alloys. The relationship between log strain and log stress follows the liner rate low. The stress exponent and the total creep strain of the Zr-based alloys are summarized in Table 1. The stress exponent value of the Zr-based alloys was about 3 to 5 in the region of the tested temperature and applied stress. This range of the stress exponent corresponds to region Ⅲ which was clearly indicated by a control of the dislocation glide as the rate-controlling mechanism. On the basis of this result, it could be assumed that the creep mechanism of the Zr-based alloys was controlled by the dislocation glide. So, it is necessary that a TEM observation on the crept specimens is performed to obtain the creep mechanism

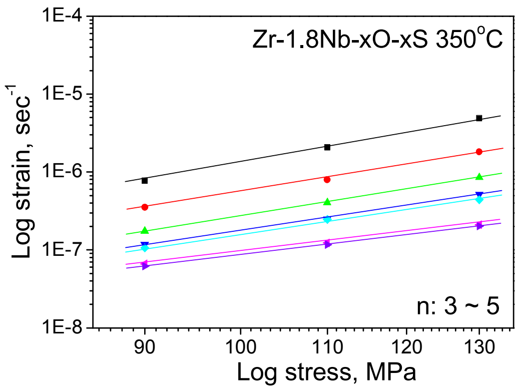

Fig 3. Log plot of creep strain vs. stress at various temperatures of Zr-based alloys

Table 1. Stress exponent and the total creep strain of the Zr-based alloys.

Factors / Alloys	Stress exponent, *n*	Total strain, %		
		90MPa	110MPa	130MPa
Zr-1.8Nb-770(ppm)O	5.02	1.53	5.02	14.59
Zr-1.8Nb-1220(ppm)O	4.42	0.98	2.09	4.37
Zr-1.8Nb-1440(ppm)O	4.45	0.44	1.28	2.75
Zr-1.8Nb-1700(ppm)O	4.5	0.33	0.75	1.62
Zr-1.8Nb-1440(ppm)O-5.9(ppm)S	3.5	0.36	0.78	1.3
Zr-1.8Nb-1440(ppm)O-18.4(ppm)S	3.1	0.2	0.39	0.63
Zr-1.8Nb-1440(ppm)O-31.5(ppm)S	3.2	0.19	0.36	0.59

3. Conclusion

The creep characteristics of the Zr-1.8Nb-xO alloys and the Zr-1.8Nb-0.144O-yS alloys were evaluated at the stress ranges from 90 to 130 MPa and at a temperature of 350℃. From the creep strength result of those alloys, increment of the O or S content showed a good effect on the creep resistance alloying elements. The creep mechanism of the Zr-1.8Nb-xO and Zr-1.8Nb-xO-yS zirconium alloys containing sulfur and oxygen was controlled by the dislocation creep mechanism glide from the results of the stress exponent values.

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